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Friction Factor in the Mine Airways of Different Wall Support

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Abstract: This study is concerned with the investigation of the friction factor between the airflow and the lining in an excavation in a typical mine. This study is based on in-situ measurements, laboratory tests, and theoretical analysis. The results are critically compared and practical conclusions are drawn.

Key words: Friction, resistance, ventilation

INTRODUCTION

In excavation works, with depth increase, the ventilation network becomes more complicated as far as the aerodynamic resistance is concerned. The airflow in the underground excavation would have to exceed the aerodynamic resistance. This resistance to air movement is designed by (R), which depends not only on the geometric parameters of the airway but also on the state of the surface of the lining (roughness)[1]. (R) is expressed as:

$$R = \alpha.\left(\frac{L.P}{S^3}\right) \tag{1}$$

Where, L, P, S: are, the length of the airway (m), airway perimeter (m) and the cross-sectional area (m^2) respectively; α is the Coefficient, which represents the loss of the energy, caused by air friction against the walls

This study is focused on the coefficient (α), which depends on the state of the wall surface of different lining. The study gives a summary of the research work carried out.

A comparison of calculated friction factors is described in this study for three Algerian mines, in order to explain the problem, and show the level of the difficulty, which mine ventilation represents. At the same time, a solution to the problem is suggested in order to minimise the friction coefficient (α).

An analysis of the friction factor will help us better understand it. The following cases are considered:

- Smooth ducts
- Rough ducts
- Mine airways

In all three cases, the study is focussed on the airflow regime that is characterised by the Reynolds's number:

$$R_e = \frac{v.D}{\nu} \tag{2}$$

Where: v, is air velocity ($m\ s^{-1}$)
D, is hydraulic mean diameter (m)
ν, is coefficient of kinematic air viscosity ($m^2\ s^{-1}$)

Airflow in the mine airways: The air cannot be considered as an incompressible fluid, it is still possible to apply the incompressible fluid equations, if the ducts of the flow are designed such as the air density varies slightly from one point to an other of the airway.

The order of error committed by this assumption is in the range of 5 to 7 %, which can be considered to be an acceptable error. In order to merely account for the resistance due to the friction of the air against the airway walls, we assume that the airflow throughout a straight and horizontal airway, with constant area and without congestion. In this case we can apply Bernoulli's law[2]:

$$\left(p_1 - p_2\right) + \left(\gamma_1.z_1 - \gamma_2.z_2\right) + \left(\frac{\gamma_1.v_1 - \gamma_2.v_2}{2.g}\right) = \Delta h \tag{3}$$

Where (Δh), represents the total energy of all external forces during the movement of a certain volume of air. For the real conditions in the mine we take: $v_1 = v_2$; $z_1 = z_2$ and γ = constant

In this case, Eq. (1) becomes:

$$p_1 - p_2 = \Delta h = \int_I^{II} dh \tag{4}$$

Figure 1, may be expressed in terms of the force of friction (H_{fr}) per unit length (dx):

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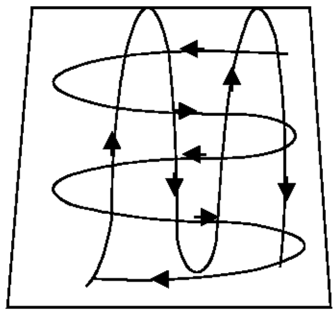

Fig. 1: Sweep method

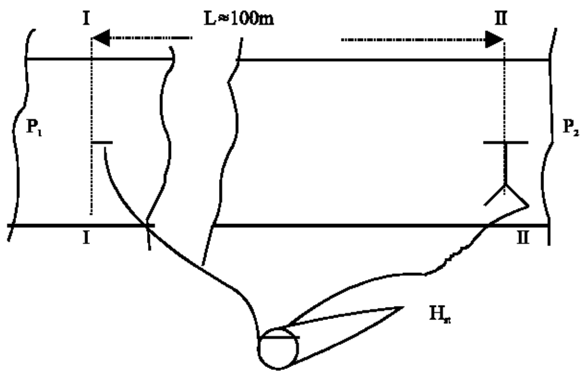

Fig. 2: Schematic of the differential static pressure measurement

$$dh = H_{fr}.dx \tag{5}$$

Since (dh) represents the work of the friction forces per unit length, then (H_{fr}) will become the friction force per unit volume. This may be expressed as:

$$H_{fr} = \frac{\tau.p_1}{s_1} \tag{6}$$

Where: τ, is the shear stress
p_1, cross sectional area of the lining per unit length
S_1, volume of the airway by unite of length

The combination of Eq. 4, 5 and 6 gives:

$$p_1 - p_2 = \frac{p}{s}.\int_{I}^{II} \tau.dx \tag{7}$$

From hydraulic concepts we also know that:

$$\tau = \beta.\rho.\left(\frac{v^2}{2}\right) \tag{8}$$

Where: β, is the friction coefficient (dimensionless), ρ, air density and v, mean air velocity

$$\beta = \frac{E_{fric}}{E_{kine}} \tag{9}$$

Where: E_{fric}, friction energy
E_{kine}, kinetic energy

$$h = p_1 - p_2 = \frac{\beta}{2}.\frac{\rho.p.L}{s}.v^2 \tag{10}$$

Where:

$$\rho = \frac{\gamma}{g} \tag{11}$$

and

$$v = \frac{Q}{s} \tag{12}$$

Then:

$$h = \frac{\beta.\gamma}{2.g}.\frac{p.L}{s^3}.Q^2 \tag{13}$$

$$\alpha = \frac{\beta.\gamma}{2.g} \qquad (kg.s^2/m^4) \tag{14}$$

α, is called the friction factor

$$h = \alpha.\frac{L.p}{S^3}.Q^2 \tag{15}$$

It can be seen from Eq. 15 that the value of (h) depends on the shape of the cross section. This latter gives the value of the perimeter (P), for a given constant section (S).

Measurement of in-situ aerodynamic parameters: In this study we describe the methods used to measure the atmospheric and ventilation parameters of three Algerian mines namely Ain mimoun, Kherzet youcef and Elabed. It is essential to present the means ant techniques used, where the accuracy of the results depends especially on the quality of the apparatus and the methods of measurements used.

The determination of these parameters will allow us to calculate the numerical values of the aerodynamics resistance of each airway being considered and the following equation is used[3]:

$$\alpha = \frac{H_{st}.S}{L.P.v^2} \tag{16}$$

Where: H_{st}, is the differential static pressure (mm.c.w)
S, L, P, are respectively the cross-section (m^2), the length (m) and the perimeter (m) of the airway
V, is air velocity ($m\ s^{-1}$)

The Methods used for the determination of the parameters are as follows:

Measurement of the air velocity (Sweep method) Simode, 1962: This method consists of sweeping the airflow with the anemometer as shown in Fig. 1.

An operator will be standing in the middle of the airway facing the airflow direction and handling the anemometer with the arms stretched forward describing a trajectory as shown in Fig. 1.

During the determination of the air velocity, the initial indication of the apparatus has to be taken after that we turn on the anemometer by mean of fans in parallel we fixed the time at about an average of 100 s. We sweep the airflow in the direction as shown in Fig. 1. After each measure, we calculate the difference between the final and the initial records, we repeat this operation two to three times.

In the beginning of the measurement we have to take the record in three scales of the anemometer (thousands, hundreds and the units), after that we turn on the anemometer by mean of the fans, which unlock the meter and the chronometer in order to fix the time (t). After recording the time and the final indication on the anemometer, we calculate the number of divisions per second with the following equation:

$$N = \frac{N_{fin} - N_{init}}{t} \qquad \text{(div/s)} \qquad (17)$$

Where :

N_{fin} is the final reading, N_{init} is the initial reading and t is the time of measurement

The value of (N) (div s^{-1}), allows us to find the air velocity using the conversion curves that come with the anemometer.

Pressure measurment Brian and Loomis, 2004: To measure the depression between two parts of the airway, we must choose one site that fulfills the following conditions:

- Constant area over a distance of 60 to 120 m in average
- No congestion is allowed in the considered airway, such as (conveyor, automatic machine, etc…)
- A regular wall support

Based on Bernoulli's Eq. (3) and the conditions mentioned above we can assert that the static differential pressure solely determines the energy loss.

This measurement is obtained by placing two pitot tubes distant 70 m apart. These are linked to a micro manometer using two flexible (5 mm diameter) pipes.

GEOMETRICAL PARAMETERS MEASUREMENT

In order to determine the value of the coefficient (α), the geometrical characteristics of the airway such as its length, area and perimeter need to be measured. The coefficient (α) is given by:

$$\alpha = \frac{H_{st}\ .\ S^3}{P\ .\ L\ .\ Q^2} \qquad (18)$$

The precision of calculating the above coefficient is much dependant on the precision in measuring the parameters (L), (P) and (S). Given that (S) is a cubic factor in the formula (18), its influence on the result is the most significant. Measuring the distance between the two pitot tubes is achieved by chaining using a double decameter. This method leads to a higher precision.

Measuring the airway's area and perimeter: The most accurate measurement is required for the section of the airway. This is due to the fact that the shape of the cross section in mine workings is usually irregular and causes measurement errors. For this reasons an indirect measuring technique is used to reduce errors below 10%. The indirect method is realised by means of a dispositif called photoprofil. This apparatus allows us to shine the perimeter of the cross-section area of the airway. A picture is taken with a camera after processing the film the border of the mine working appears shining by mean of the photoprofil.

The result of the measurement and calculation are shown.

PHYSICAL PROTOTYPE

The study of the physical prototype is based on the knowledge and the calculation of the simulation criteria, which are:

- Geometric similarity
- Kenitic similarity
- Dynamic similarity

The apparatus used during the simulation:

- Micro- manometer
- Psychometer
- Barometer
- Three pitot tubes and flexible pipe

Prototype description: Made on 1/20 scale, the airway has a trapezoidal shape, made of wood and supported by wooden frame of 5,10, and 15 mm, 20 mm for a squared frame and 20 mm diameter for a circular frame. The test was that we have to change only the distance between the support frame (l).

RESULTS AND DISCUSSIONS

The results of the laboratory work are presented in Fig. 3 and 4. It has been noticed from the experimental work and the in-situ measurement that for the same shape of frame the results are nearly similar. Then , from the experimental results the monogrammes are drawn to determine the friction factor in function of the relative roughness of the airway and the value of (l/D). These monogrammes are presented in Fig. 5 and 6.

This study was related to the variations of the value of (α) representing the coefficient characterizing the roughness surface state and consequently its influence on aerodynamic braking of the air draught.

The value of (α) varies in broad measurement; that one can decrease up to 80%, by panels of garnishing out of plastic.

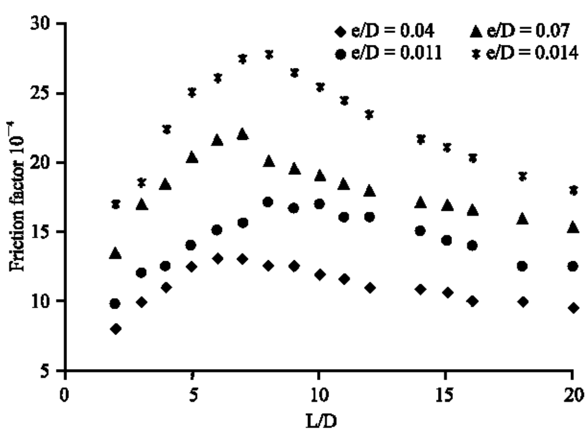

Fig. 3: Experimental results of the friction factor in fomction of the l/D and the relative roughness (squared frame)

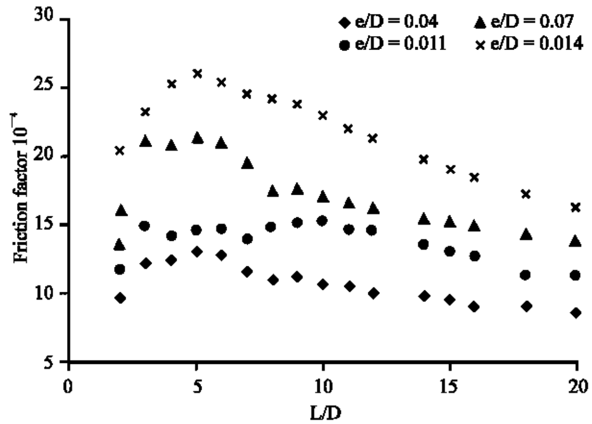

Fig. 4: Experimental results of the friction factor in function of the l/D and the relative roughness (circular frame)

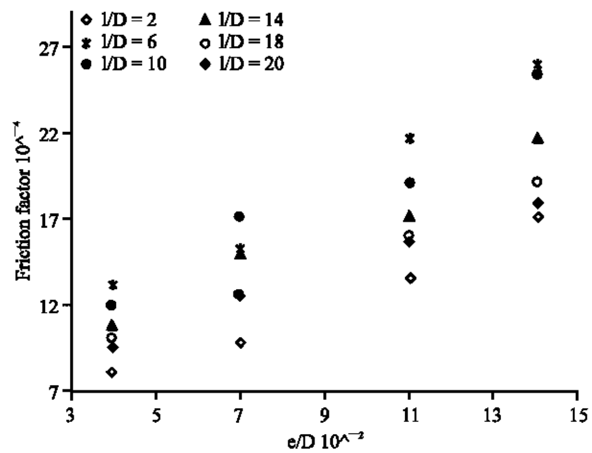

Fig. 5: Nomogramme of determination of friction factor in fonction of the relative roughness for squared frame

To decrease to a minimum value of (α),will have a double aspect economic as well as hygienic, due to energy saving, accompanied to the respect of the established medical standards.

The ideal form of work is circular, since the ratio is minimal, which means that the coefficient form is equal to 1.

In this study we simulated the work area of 60 m length and a section equal to 12 m^2, the model is on a scale of (1/20), a trapezoidal shape and supported by circular and squared frames of various diameters and various ratio (l/D).

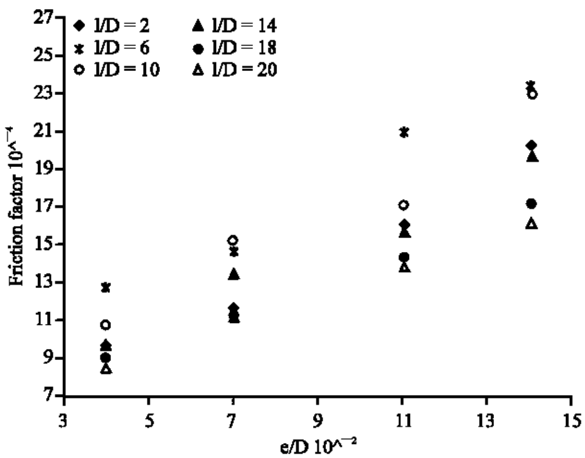

Fig. 6: Nomogramme of determination of friction factor in fonction of the relative roughness for circular frame

The monograms were drawn by interpolation methods show clearly that:

(α) increases if (ε/D) increases

(α) = maximum if 5< (l/D) < 7 for the squared frame

(α) = maximum if 4 < (l/D) < 6 for the circular frame

where: (ε/D) is the relative roughness and (l/D) is the longitudinal gauge.

CONCLUSION

It should be noticed, that it is necessary to determine by stability calculations of the work ratio (l/D) in order to compare it with the lowest corresponding value of (α).

These monograms help engineers to find the value of the friction factor during the ventilation networks project.

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